Physiologically Inspired Blinking Behavior for a Humanoid Robot

Hagen Lehmann[1(✉)], Alessandro Roncone[2], Ugo Pattacini[1], and Giorgio Metta[1]

[1] Istituto Italiano di Tecnologia, iCub Facility, via Morego 30, 16163 Genoa, Italy
`hagen.lehmann@iit.it`
[2] Social Robotics Lab, Yale University, 51 Prospect Street, New Haven, CT 06511, USA

Abstract. Blinking behavior is an important part of human nonverbal communication. It signals the psychological state of the social partner. In this study, we implemented different blinking behaviors for a humanoid robot with pronounced physical eyes. The blinking patterns implemented were either statistical or based on human physiological data. We investigated in an online study the influence of the different behaviors on the perception of the robot by human users with the help of the Godspeed questionnaire. Our results showed that, in the condition with human-like blinking behavior, the robot was perceived as being more intelligent compared to not blinking or statistical blinking. As we will argue, this finding represents the starting point for the design of a ‘holistic’ social robotic behavior.

Keywords: Social robotics · iCub · Human-like blinking behavior · Online study · Godspeed questionnaire · Humanoids robotics

1 Introduction

One of the ambitions of current research in social robotics is generating solutions to counteract the demographic changes that human societies are facing around the globe [1]. Today transformations such as the childbirth peak and the increment of the present-day underrepresented age groups of 50 to 70, as well as 70 and above, lead to a predicted increase of the human population to 11 billion in the next 100 years [2]. This prediction produces the request of significant changes in our elderly care strategies to make our health care systems sustainable in the imminent future, and social robotics is one of the forces that can effectively participate to this process of renewal.

Recent advancements in the design and development of social robots will lead in the next years to commercial products able to stimulate the first steps towards the creation of “mixed human-robot ecologies” [3], in which robots will use social competences to better accomplish interactive tasks in service domains such as elderly care, personal assistance, health services, etc.

Currently, the ways these robotic agents should look like and behave are highly debated topics of research. One of the main research directions develops the idea that social robots should have an approximately humanoid appearance (i.e., possessing at least a head, arms and a torso [4]), and behave and move in naturalistic human-like ways defined by human social rules and characteristics [5]. This would assure that the

A. Agah et al. (Eds.): ICSR 2016, LNAI 9979, pp. 83–93, 2016.
DOI: 10.1007/978-3-319-47437-3_9

interactions between these robots and their human partners will be highly intuitive, comfortable and reassuring. Specifically, in fields involving vulnerable individuals, such as elderly care and health services in general, human-like social components of the interaction are considered fundamental for the acceptance of robotic agents [6].

On this basis, contemporary research is focusing, besides on the “static” design and appearance of these robots, on the definition of their socially interactive movements and behaviors. This is considered particularly important when constructing humanoids, in order to avoid that these robots “fall” into the “uncanny valley” [7]. Typically, humanoids raise the expectation of behaving like humans, and tend to be perceived as disturbing and fearsome when exhibiting unnatural movements and behaviors. More in general, to ensure a positive perception of the robots and their integration in our social environments, the naturalness and intuitiveness of the “interaction interface” is highly important. For humanoid robots, this interaction interface is going to be their physical body, socially activated by body language, facial expressions and verbal communication.

In this paper, we will illustrate the first step of a structured approach to the integration of human-like nonverbal involuntary behavior in humanoid social robots. The target behavior is human-like eye blinking, based on the hypothesis that, to stimulate intuitive and comfortable conversations with humanoid robots endowed with expressive faces that include physical eyes, naturalistic eye blinking plays a very important role. We tested this hypothesis by means of an online experiment, in which we presented videos of the iCub robot exhibiting different blinking patterns during a conversation and asked our participants to rate them according to the personal impression.

We will describe the research process that supported our implementation and evaluation of a human-like conversational blinking pattern in detail. We consider this work as the starting point of a multimodal integrative approach to the implementation of human-like non-verbal communication behaviors in social robots. According to this approach, we are defining for iCub a behavioral library based on the experimental exploration of human socially interactive behaviors, and later we will proceed to coordinately integrate in the robot the different behavior modalities included in our studies and library.

2 Background

Basic behavior synchronization in humans is achieved on the basis of observation of the behaviors exhibited by a social partner, and neuronal mechanisms such as the mirror neuron system [8]. The processing of this behavior might happen consciously or unconsciously, but the result remains a behavioral synchronization that facilitates mutual understanding and cooperation between the interaction partners. We propose that for artificial agents it would be sufficient to observe and to respond to observed behaviors accordingly, in order to facilitate conversations and cooperation with their users.

Even before the advent of the research field of social robotics, it was shown that reactive nodding and blinking of a simulated artificial agent facilitates the turn taking and smoothness of human speech input to computers [9, 10].

The role of blinking has been recognized as important in the field of social robotics very early on [11]. This has encouraged researchers in the field to explore the potentialities of blinking in human robot communication [12]. Specifically, for robots like the iCub, featuring pronounced physical eyes, authentic eye blinking behavior can have a profound impact on the interaction comfort [13]. Eyelids have been implemented into different social robots [e.g. 14, 15]. Nevertheless, there have only been very few structured inquiries on how to model human blinking for robots with physical eyes and the blinking behavior has mainly been added randomly into the social interaction with these robots [e.g. 12]. This is largely due to the technical restraints physical robotic human-like eyes impose and to the complexity of factors influencing blinking in humans.

In the last decades, physiological research on the various dependencies of human eye blinking behavior on different physiological and psychological factors produced a variety of results that can be used to model blinking in social robots. Ford et al. [16] showed for example that blinking is strongly linked to onsets and offsets of communicative facial behaviors and verbalizations. Based on their findings, they proposed the "blink model" for HRI, which integrates blinking as a function of communicative behaviors. In their experiments they used a back projected face on a human face mold. Doughty [17] described in his work three distinct blinking patterns during reading, dialoging and idly looking at nothing specific. Lee et al. [18] proposed a model of animated eye gaze that integrates blinking as depending on eye movements constituting gaze direction. Neurological findings showed that responses to facial movements such as blinks can be measured in an observer's brain [19], a result that hints at the social importance of eye blinking for behavior synchronization between social interlocutors.

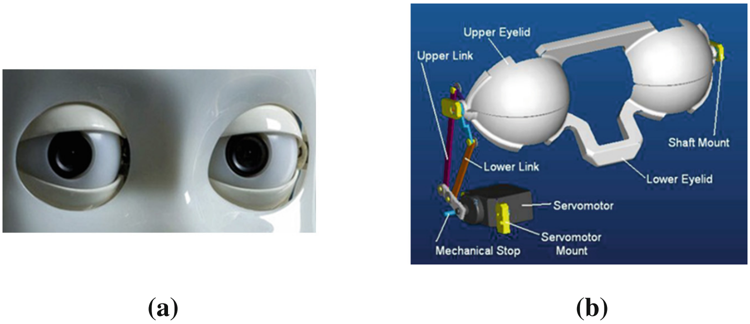
In summary, it can be said that blinking has been described as: (1) a function of physiological variables, such as the average speed of a single blink, the average blinking rate and the average length of the inter eye blink intervals (IEBI); (2) a function of system state variables, such as changes in facial expression and verbal communication behaviors; (3) a function of social context information, such as reading and being in a conversation; (4) a function of the psychological state of the person exhibiting the behavior; and (5) a function of the behavior of the social interlocutor.

As part of a holistic non-verbal behavior architecture for the iCub robot we started to develop a module for human-like conversational blinking - "BlinkSync" [20] - in which the robot blinking is based on human physiological data. In order to achieve human-like conversational blinking, we integrated as a first step the average speed of a single blink, the average blinking rate and the average length of the inter eye blink intervals into "BlinkSync".

3 Method

We used human social behavior data to model social behaviors for the robot, and then to test these behaviors in Human-Robot Interaction contexts. We used both an optimization approach for the behaviors on the robot and a synthetic modeling approach for the testing of these behaviors in natural environments.

iCub Eyelid Mechanism. For the implementation and testing of our blinking module we used the iCub robot. It has very pronounced eyes resembling human features like a black pupil, white sclera, and moveable upper and lower eyelids (Fig. 1a).



(a) **(b)**

Fig. 1. (a) iCub eyes and (b) iCub eyelid mechanism

The eyelid mechanism is controlled by one servomotor and constructed in such a way that both eyes close at the same time and the eyelids meet in the center of the eyeballs (Fig. 1b). The servomotor is a standard model from Futaba and controlled with a pulse-width modulation (PWM) input. The motor is driven by a PWM control signal with a frequency of 50 Hz. The duration of the pulse determines the final position of the motor shaft. The motor will move to the "0°" position when the pulse has a width of 1 ms. The position of "90°" is reached for a pulse duration of 2 ms.

The eyelids can be controlled continuously from an open position to closed position. Commands can be given to open or close the eyelids from totally closed to totally open, with 127 levels of discretization [21].

Human-Like Blinking. For the human-like blinking behavior, we chose to use as a starting point the physiological data provided by Doughty [17] and to adapt it to technical limitations of the iCub eyelid mechanism. The general settings for the conversational blinking module are an average blinking rate of 23.3 blinks per minute with an inter eye blink interval of 2.3 ± 2.0 s. The blinks of the robot are in 85 % of the cases single blinks and in 15 % of the cases double blinks.

We divided each blink into three phases, the attack phase when the eye is closing, the sustain phase when the eye is closed, and the decay phase when the eye is opening again. The attack phase has an average length of 111 ms with a standard deviation of 31 ms. The sustain phase lasts on average 20 ms with a standard deviation of 5 ms. The average length of the decay phase is 300 ms with a standard deviation of 123 ms. The robot also blinks on each onset and offset of its verbalizations.

The adaptation of the original physiological data from Doughty became necessary due to the specifics of the iCub eyelids. Unlike in a human eye, the robot's upper and lower eyelids move the same way during the blink. When using the original human data, this results in a much faster closure of the eye (the eyelids meet in the middle of the eyeball). This resulted in what was described by participants in a short pilot study as hectic blinking. By adapting the different speeds of each of the phases it was possible to give the movement a more human-like appearance.

The code for the blink controller was implemented and released under the GPL open source license on GitHub (The source code is accessible at https://github.com/robotology/funny-things/tree/master/modules/iCubBlinker, and the documentation can be found at http://robotology.github.io/funny-things.). It was developed for the iCub humanoid robot, and is readily available for any iCub robot. The architecture is generically applicable to any humanoid head, and the code has been designed to be modular and easy to adapt to any other robotic platform.

Experimental Setup. In order to evaluate influence of the blinking behavior on the impression the robot has on participants we generated three conditions with different blinking patterns. For the robot to appear to be in a social interaction during the experiment, we scripted a one-interview. In order to make this interview interesting and informative for the participants watching it, we decided to “discuss” with the robot a game it plays usually during demonstrations and exhibitions. The questions asked in this interview and the robots answers were the same in each of the three experimental conditions.

- Condition 1: The robot looked straight ahead without blinking while answering the questions of the experimenter.
- Condition 2: The robot blinked every 5 s using the timings for the attack, sustain, and decay phases described in *Human-like blinking*. It performed no double blinks.
- Condition 3: The robot blinked with a rate of 23.3 blinks per minute. It performed double blinks and blinked at the onset and offset of its verbalizations. The timing was of the three phases of the blink were as described in *Human-like blinking*.

We recorded each of the conditions in such a way that the potential participant watching the video would see a front view of the robot (see Fig. 2) and hear both the interviewer and the robot talk. The participants would hear the experimenter asking the questions to the robot, but would not see him.

In order to reach as many participants as possible in a short time we chose an online video study as format for our experiment. The Video-based HRI (VHRI) methodology has been used reliably in several human-robot interaction studies in the past [e.g. 22]. In a direct comparison of live HRI and Video-based HRI, it has been shown that comparable results can be achieved [23].

The videos were embedded in an online questionnaire in which we asked the participants first for their consent, then for their demographic data and their experience with robots. After this first part, each participant would see the video clip of one of the conditions. Which condition the participant would see was randomly chosen. After the participants watched the video clip, they were asked to complete an online version of the *Godspeed Questionnaire* [24]. In order to recruit participants, the link to the online study was sent to different mailing lists in Europe. The survey was prepared with Google Forms.

The *Godspeed Questionnaire* [24] evaluates the impression a person has of a robot on five different subscales. These subscales are anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety. Since we hypothesize that the blinking behavior will improve the user experience with the robot, we expected that in condition 3 the robot would score higher compared to condition 1 and condition 2 in anthropomorphism, animacy, likeability and perceived intelligence.

4 Results

Sample Characteristics. We received 44 replies to our call for help of which 26 were male and 18 were female. The mean age of the participants was 34.98 years, ranging from 24 to 56. Most of them had seen at least pictures of the iCub before. Concerning their experience with robots 21 reported none, 12 reported little, 10 reported some experience, and only one participant indicated that his experience with robots was substantial.

Godspeed Questionnaire Results. In order to test our research hypothesis, we examined the differences in participant ratings of the robot along the subscales of the Godspeed Questionnaire. It has been shown that this is valid procedure when analyzing this questionnaire [25]. The descriptive statistics for Anthropomorphism can be seen in Table 1.

Table 1. Descriptive statistics anthropomorphism

Condition	Variable	Mean (SD)	Median
Condition 1	Anthropomorphism	2.63 (0.23)	2.71
Condition 2	Anthropomorphism	2.71 (0.43)	2.78
Condition 3	Anthropomorphism	2.65 (0.45)	2.44

For anthropomorphism the participants overall rated the robot in none of the 3 conditions higher than the “neutral” score of 3. A single factor ANOVA found no significant differences between the three conditions (F(2,12) = 0.07, p = 0.94).

The descriptive statistics for animacy are presented in Table 2. For animacy, the participants rated the robot both in condition 2 and 3 higher than the “neutral” score of 3. In condition 1, the robot was overall rated lower then neutral. A single factor ANOVA found no significant differences between the three conditions (F(2,15) = 0.42, p = 0.66).

Table 2. Descriptive statistics animacy

Condition	Variable	Mean (SD)	Median
Condition 1	Animacy	2.8 (0.67)	2.78
Condition 2	Animacy	3.04 (0.76)	3.07
Condition 3	Animacy	3.19 (0.76)	3.28

The descriptive statistics for likeability are presented in Table 3. For likeability, the robot was rated in all three conditions higher than the “positive” score of 4. A single factor ANOVA found no significant differences between the three conditions (F(2,12) = 0.38, p = 0.69).

Table 3. Descriptive statistics for likeability

Condition	Variable	Mean (SD)	Median
Condition 1	Likeability	4.11 (0.17)	4.07
Condition 2	Likeability	4.16 (0.15)	4.07
Condition 3	Likeability	4.08 (0.11)	4.06

The descriptive statistics for perceived intelligence are presented in Table 4. For perceived intelligence the participants overall rated the robot in all of the three conditions higher than the "neutral" score of 3. A single factor ANOVA found significant differences between the three conditions (F(2,12) = 6.3, p = 0.01).

Table 4. Descriptive statistics perceived intelligence

Condition	Variable	Mean (SD)	Median
Condition 1	Perceived intelligence	3.37 (0.27)	3.43
Condition 2	Perceived intelligence	3.6 (0.19)	3.57
Condition 3	Perceived intelligence	3.89 (0.22)	3.94

The descriptive statistics for perceived safety are presented in Table 5. For perceived safety the participants overall rated the robot in all of the three conditions higher than the "neutral" score of 3. A single factor ANOVA found no significant differences between the three conditions (F(2,6) = 0.01, p = 0.99).

Table 5. Descriptive statistics perceived safety

Condition	Variable	Mean (SD)	Median
Condition 1	Perceived safety	3.74 (0.41)	3.86
Condition 2	Perceived safety	3.69 (0.48)	3.93
Condition 3	Perceived safety	3.73 (0.16)	3.75

5 Discussion

Our results show that the robot, when displaying human-like blinking, was perceived as being more "intelligent" according to the categories of the Godspeed questionnaire. For its other subscales, no significant differences were found. This illustrates that even though human-like blinking behavior can make a significant difference in how humans perceive robots, it is only one aspect of human nonverbal communication that needs to be taken in consideration when designing social behaviors for robots. Naturalistic blinking in itself it is not enough for a robot to meet the requirements for its social integration, such as for example perceived safety, likeability, and animacy. We could think to blinking as an important, but not a sufficient characteristic regarding social integration.

Being perceived as intelligent can be advantageous for the effectiveness of a robot specifically in situations in which it has to transmit information in a social context, e.g. when the robot is used as a guide or informant in shopping malls, train stations or in tourist information centers. A robot that is perceived more intelligent is likely to be considered more competent and trustworthy in these cases.

During the study, we discovered a series of issues that influenced and even limited our implementation of the blinking behavior on the robot. One of the issues was the noise of the motor and the eyelids when closing. This disturbed the flow of the interaction and, as pointed out by one participant, “made the eyes look and sound like the shutter of a camera”. For future versions of iCub’s embodiment (and other robots with structured physical eyes) this should be taken into consideration and the blinking mechanism should be constructed accordingly.

Another question asked by some of the participants was whether the iCub can wink or not. Due to the construction of the eyelid mechanism, this is not possible at the moment. Winking as social cue is already being used successfully in computer-mediated communication in the form of emoticons [26]. To implement human-like winking with related triggering behavioral patterns for the iCub robot could be another key point in order to achieve positive and intuitive human-robot conversational interaction.

Due to the online format of the study, the participants were listening to a scripted conversation between the robot and the experimenter. We acknowledge that a direct conversation between the participant and the robot might have been more efficient to test the effect of naturalistic blinking behavior. As pointed out in the *Experimental Setup* section, we argue that similar results would be achieved with the VHRI methodology and that, in the case of a real time conversation between the robot and the human, our results would not be structurally different, but more pronounced.

The result that the naturalistic blinking behavior was more appreciated by users indicates that the synthetic methodology – i.e., modeling natural behaviors in artificial (in our case robotic) systems [27] – is a promising way to create successful applications for HRI. In other words, this methodology appears able to allow us to build better social robots, i.e. robots with a more convincing social presence, as well as to test psychological and sociological paradigms about their integration in human societies.

Future Work. Following our current research, we plan to study further how different blinking behaviors influence social interactions, by using the “Blink-Sync” module in human-robot interaction contexts (testing different blinking patterns in different situations) [20]. Applicative fields of the “BlinkSync” model, and of the “synthetic social studies” it can allow, are many, and include robot assisted therapy for children and elderly, and health care. An interesting application comes from research with children with autism spectrum disorder. Various studies have shown that using eye blinking attracts the children’s attention towards the eyes and helps maintain engagement in the therapeutic setting [e.g. 28]. Other studies showed that children with ASD show atypical blinking pattern and even the absence of blinking in conversational contexts [29]. These results are interesting, because autistic children usually avoid looking into the eyes of their interaction partners. Utilizing the effect with naturalistic eye blink patterns in this context might help to teach these children to better interpret and understand the facial expressions of their social partners, which is something that is very difficult for people with autism [30].

6 Conclusions

We see the modeling of naturalistic blinking as a first step towards a more integrated nonverbal social communication approach. The result of our study shows that the implementation of naturalistic blinking behavior has a positive impact on the perception of the robot by a human user. In general, it can be said that the information transferred by the movement of the eyelids of a robot is important for a smooth and intuitive interaction between a human and a robot. Nevertheless, it is important to understand blinking only as part of the nonverbal social information transmission channel, with for example eye gaze direction or gestures at least as equally important [31, 32].

Acknowledgment. This research was funded by the EU via the Marie-Sklodowska Curie Action Program (SICSAR - grant agreement n° 627688).

References

1. United Nations. World Population Prospect – Revision 2015. United Nations, New York (2015)
2. http://www.gapminder.org/
3. Damiano, L., Dumouchel, P., Lehmann, H.: Towards human-robot affective co-evolution overcoming oppositions in constructing emotions and empathy. Int. J. Soc. Robot. **7**, 7–18 (2014). doi:10.1007/s12369-014-0258-7
4. Walters, M.L., Syrdal, D.S., Dautenhahn, K., Te Boekhorst, R., Koay, K.L.: Avoiding the uncanny valley: robot appearance, personality and consistency of behavior in an attention-seeking home scenario for a robot companion. Auton. Robot. **24**, 159–178 (2008)
5. Boucher, J.D., Pattacini, U., Lelong, A., Bailly, G., Elisei, F., Fagel, S., Dominey, P.F., Ventre-Dominey, J.: I reach faster when i see you look: gaze effects in human-human and human-robot face-to-face cooperation. Front. Neurorobot. **6**(3), 1–11 (2012)
6. Lehmann, H., Syrdal, D.S., Dautenhahn, K., Gelderblom, G., Bedaf, S., Amirabdollahian, F.: What should a robot do for you? - Evaluating the needs of the elderly in the UK. In: Sixth International Conference on Advances in Computer-Human Interactions (ACHI 2013), pp. 83–88 (2013)
7. Mori, M.: Bukimi no tani [the uncanny valley]. Energy **7**, 33–35 (1970)
8. Rizzolatti, G., Fogassi, L., Gallese, V.: Neurophysiological mechanisms underlying the understanding and imitation of action. Nat. Rev. Neurosci. **2**, 661–670 (2001)
9. Watanabe, T., Yuuki, N.: A voice reaction system with a visualized response equivalent to nodding. In: Proceedings of the Third International Conference on Human-Computer Interaction, vol. 1 on Work with Computers: Organizational, Management, Stress and Health Aspects. Elsevier Science Inc., pp. 396–403 (1989)
10. Watanabe, T., Higuchi, A.: Facial expression graphics feedback for improving the smoothness of human speech input to computers. Adv. Hum. Factors/Ergon. **18**, 491–497 (1991)
11. Breazeal, C.: Toward sociable robots. Robot. Auton. Syst. **42**, 167–175 (2003)
12. Yoshikawa, Y., Shinozawa, K., Ishiguro, H., Hagita, N., Miyamoto, T.: The effects of responsive eye movement and blinking behavior in a communication robot. In: 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 4564–4569. IEEE (2006)

13. DiSalvo, C., Gemperle, F., Forlizzi, J., Kiesler, S.: All robots are not created equal: the design and perception of humanoid robot heads. In: Proceedings of Designing Interactive Systems, pp. 321–326 (2001)
14. Dautenhahn, K., Nehaniv, C.L., Walters, M.L., Robins, B., Kose-Bagci, H., Mirza, N.A., Blow, M.: KASPAR–a minimally expressive humanoid robot for human–robot interaction research. Appl. Bion. Biomech. **6**(3–4), 369–397 (2009)
15. Metta, G., Natale, L., Nori, F., Sandini, G., Vernon, D., Fadiga, L., Von Hofsten, C., Rosander, K., Lopes, M., Santos-Victor, J., Bernardino, A.: The iCub humanoid robot: an open-systems platform for research in cognitive development. Neural Netw. **23**(8), 1125–1134 (2010)
16. Ford, C.C., Bugmann, G., Culverhouse, P.: Modeling the human blink: a computational model for use within human–robot interaction. Int. J. Hum. Robot. **10**(01), 135006 (2013)
17. Doughty, M.J.: Consideration of three types of spontaneous eyeblink activity in normal humans: during reading and video display terminal use, in primary gaze, and while in conversation. Optom. Vis. Sci. **78**(10), 712–725 (2001)
18. Lee, S.P., Badler, J.B., Badler, N.I.: Eyes alive. ACM Trans. Graph. **21**, 637–644 (2002)
19. Brefczynski-Lewis, J.A., Berrebi, M., McNeely, M., Prostko, A., Puce, A.: In the blink of an eye: neural responses elicited to viewing the eye blinks of another individual. Front. Hum. Neurosci. **5**, 1–8 (2011)
20. Lehmann, H., Pattacini, U., Metta, G.: Blink-sync: mediating human-robot social dynamics with naturalistic blinking behavior. In: Workshop on Behavior Coordination Between Animals, Humans and Robots; 10th ACM/IEEE International Conference on Human-Robot Interaction (2015)
21. Bernardino, A., Nunes, R., Vargas, L., Beira, R., Lopes, M., Santos-Victor, J.: Expressions system control for the iCub head (Internal Report No. 004370). Instituto Superior Tecnico (2007)
22. Lohse, M., Hanheide, M., Wrede, B., Walters, M.L., Koay, K.L., Syrdal, D.S., et al.: Evaluating extrovert and introvert behaviour of a domestic robot — a video study. In: The 17th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN 2008), pp. 488–493. IEEE, August 2008
23. Woods, S.N., Walters, M.L., Koay, K.L., Dautenhahn, K.: Comparing human robot interaction scenarios using live and video based methods: towards a novel methodological approach. In: Proceedings of the 9th International Workshop on Advanced Motion Control (AMC 2006), 27 – 29 March, Istanbul (2006)
24. Bartneck, C., Kulić, D., Croft, E., Zoghbi, S.: Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. Int. J. Soc. Robot. **1**, 71–81 (2009). doi:10.1007/s12369-008-0001-3
25. Lehmann, H., Saez-Pons, J., Syrdal, D.S., Dautenhahn, K.: In good company? perception of movement synchrony of a non-anthropomorphic robot. PLoS ONE **10**, e0127747 (2015). doi: 10.1371/journal.pone.0127747
26. Derks, D., Bos, A.E., Von Grumbkow, J.: Emoticons in computer-mediated communication: social motives and social context. CyberPsychol. Behav. **11**, 99–101 (2008)
27. Damiano, L., Hiolle, A., Cañamero, L.: Grounding synthetic knowledge. In: Lenaerts, T., Giacobini, M., Bersini, H., Bourgine, P., Dorigo, M., Doursat, R. (eds.) Advances in Artificial Life (ECAL 2011). MIT Press, Cambridge (2011)
28. Robins, B., Dautenhahn, K., Dickerson, P.: From isolation to communication: a case study evaluation of robot assisted play for children with autism with a minimally expressive humanoid robot. In: 2009 Second International Conferences on Advances in Computer-Human Interactions (ACHI 2009), pp. 205–211. IEEE (2009)

29. Nakano, T., Kato, N., Kitazawa, S.: Lack of eyeblink entrainments in autism spectrum disorders. Neuropsychologia **49**, 2784–2790 (2011). doi:10.1016/j.neuropsychologia.2011.06.007
30. Baron-Cohen, S.: Mindblindness: An Essay on Autism and Theory of Mind. MIT press, Cambridge (1997)
31. Tomasello, M., Hare, B., Lehmann, H., Call, J.: Reliance on head versus eyes in the gaze following of great apes and human infants: the cooperative eye hypothesis. J. Hum. Evol. **52**, 314–332 (2007)
32. Broz, F., Lehmann, H., Nehaniv, C.L., Dautenhahn, K.: Automated analysis of mutual gaze in human conversational pairs. In: Nakano, Y.I., Conati, C., Bader, T. (eds.) Eye Gaze in Intelligent User Interfaces, pp. 41–60. Springer, London (2013)